

Simulation: It's the Real Thing

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Introduction

Almost everyone has heard the term *simulation*, but who knows what it really means? Is simulation represented by a wargaming effort, such as Pacific Air Forces (PACAF) units participating in a TEAM SPIRIT exercise? Or, is a better example provided by a C-5 aircrew practicing emergency procedures in a cockpit mockup? Perhaps simulation is best demonstrated by somebody analyzing a computer-based model to determine the expected number of backorders of some reparable item for the Joint Strike Fighter?

Whatever simulation means, the military seems to think it is worthwhile. A few examples: *Joint Vision 2010* specifically cites simulation as a method of improving training realism, promoting readiness and assessing operations concepts.¹ The DoD Directive for defense acquisition *requires* that "modeling and simulations shall be used to reduce the time, resources, and risks of the acquisition resources."² Finally, the DoD has established a modeling and simulation master plan³ and an *entire organization* to address simulation issues.⁴

In fact, simulation includes wargaming, training and analysis. It is generally defined as a modeling *process* whereby *entities* (that is, objects of interest—which can include real people, machines or even failure or repair actions) interact in a defined way, over a period of time. The terms *modeling* and *simulation* are often used interchangeably; however, this is not really correct. A model is simply an approximate representation of some piece of our world. A model can be either *physical* (as in a miniature wooden replica of an aircraft) or *symbolic* (as in the mathematical equation of distance as a product of velocity and time). Simulation is merely one method of building and using a model. For example, other ways of building and analyzing symbolic models include the operations research optimization techniques of linear and nonlinear programming. Baker and Grabau discuss the modeling-simulation distinction in more detail in a recent issue of *Program Manager*.⁵

Simulation is used when other methods are too dangerous, too expensive or impractical. In a wargaming exercise, it is safer to pretend that someone is the enemy instead of engaging a real one and to use laser gear or paintballs instead of real munitions. Since we don't yet have operational experience with the Joint Strike Fighter (JSF), symbolic model simulations are very useful for estimating JSF support requirements. Incidentally, we generally use simulation for symbolic models only when these models cannot be solved by analytic means. This is because simulations typically give us only *approximate* solutions instead of exact values. Furthermore, it is difficult to use simulation to *optimize* a model's input values.

The remainder of this article provides an overview of simulation, with emphasis on logistics modeling. Key DoD

simulation agencies are introduced. The critical area of verification and validation is discussed, and the article concludes with recommendations for further reading.

A Simulation Taxonomy

Neyland identifies three commonly used simulation categories: *live*, *virtual* and *constructive*.⁶ Live simulation is the process of real people using real machines while pretending to perform some activity, instead of actually doing it. The TEAM SPIRIT example falls into this category. Virtual simulations still involve real people, but now they are using mockups instead of real equipment. A classic example is an aircrew using a cockpit mockup, as in the C-5 example. Finally, constructive simulations consist of models of people and machines. Constructive simulations are typically accomplished by running a symbolic model on a computer. An example would be to run the Logistics Composite Model (LCOM)—a powerful tool that is generally used to identify the best mix of logistical resources to support a given weapon system under operational constraints.⁷

Real Time

A key distinguishing characteristic between live, virtual and constructive simulations is the passage of *time*. Live and virtual simulations both use real time—one second on a wall clock is equivalent to one second of simulation time. In a live simulation such as a RED FLAG exercise, commanders and operators are able to affect the course of the simulation by periodically making decisions or taking action and then observing the effect of those actions. In contrast, constructive simulations typically use either expanded or compressed time—one second on a wall clock could be the same as either a nanosecond or a year of simulation time. For example, in just a few wall clock minutes, an analyst can use LCOM to simulate five years of base-level aircraft support activity. The problem is that after a constructive simulation's initial conditions and runtime constraints are specified, little or no human-model interaction is possible until the simulation run is complete. In our LCOM model, for example, we cannot arbitrarily hit the computer *pause* key sometime during a simulation, pretend an enemy just blew up a back-shop and then *resume* the simulation to see what happens. Instead, both the enemy attack and some feasible workaround strategies for the missing back shop would need to be scripted in, *before* the simulation begins.

A Common Technical Framework

Imagine that we have access to two virtual simulators—a desktop computer-based MiG 23 program and a \$10M F-15C motion-base dome simulator. Could we connect the two

systems and let 'em battle it out? Several issues arise: do the two simulations use the same standards for describing and sharing data? Can we synchronize the clock timing of the two simulations? Do the two simulations share a common perception of the battlespace and of each other's respective weapon system capabilities? The idea of linking a desktop computer simulator to a motion-base dome system may seem extreme, but in reality wargamers and others are increasingly interested in the ability to network live, virtual and even constructive simulations into a single effort (that is, into a *system of systems*). If the individual simulations could be truly interoperable, then the limitations of any single component simulation should be transparent to the others. For example, neither our MiG 23 pilot nor our F-15C pilot should be able to tell whether the other is flying a dome or a desktop simulator. The main difference for the two pilots should only be in the amount of realism each experiences in the simulated battle.⁸ The need to resolve interoperability issues and promote the reusability of simulations led the DoD to establish a *common technical framework* (CTF), to which individual simulation efforts must conform. The CTF is a product of the Defense Modeling and Simulation Office (DMSO), located in Alexandria, Virginia.⁹ The CTF consists of three parts:

- A *high level architecture* (HLA), which is a set of conceptual rules and specifications that prescribe how the different simulations will work together.
 - A *conceptual model* of the mission space (CMMS) which is essentially a common understanding of what the real world looks like.
 - A set of *data standards*, which includes things like physical data representation, data quality and data security.¹⁰
- Hollenbach and Alexander use the analogy of city planning to illustrate the CTF concept, noting that

... to build and operate an efficient city, a governing framework (for example, street plans, building codes, ordinances) is laid out and certain basic services (for example, utilities, schools, fire protection) are provided. Beyond that the residents are generally left to their own discretion as to what type of home or business they build, who they interact with¹¹

Systems of Systems

Military analysis can benefit from considering virtual *systems of systems*. In November 1997, the Army investigated the denial of global positioning system data on battalion-sized operations by linking four M1A1 Abrams tank simulators at the Simulation Network (SIMNET) facility at Fort Hood, Texas, with two helicopter simulators at Fort Rucker, Alabama, and a fuel truck simulator at Fort Knox, Kentucky. This virtual simulation enabled the Army to predict how soldiers could use new technologies under a variety of conditions.¹²

Wargaming activities frequently use a suite of virtual simulation models. A commonly used simulation is a two-sided theater air campaign model called Air Warfare Simulation Mode (AWSIM). It is typically used to train battle staffs and also acts as a nonscripted command post exercise driver. Another example is the corps battle simulation (CBS). CBS simulates both air and ground forces and is used for battle

staff training. Neither AWSIM nor CBS can model all aspects of a campaign and so both are frequently used in conjunction with other simulations during an exercise (for example, AWSIM does not model space-based systems or information warfare).¹³

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Logistics Realism

A principal shortcoming of wargaming simulations is that they do a poor job of modeling logistics. For example, a documented problem with AWSIM is its inadequate representation of air/ground mobility and resupply, maintenance, personnel and non-weapon consumption rates.¹⁴ In recognition of this shortcoming and to help train staff logisticians, the Headquarters United States Air Forces in Europe Deputy Chief of Staff for Logistics (HQ USAFE/LG) established the Logistics Exercise Enhancement Program (LEEP). LEEP consists of a Logistics Simulation (LOGSIM) model for replicating base-level logistics and a program of documentation and training support for injecting logistics realism into wargaming exercises. LOGSIM has supported the last three USAFE UNION FLASH exercises and HQ PACAF's ULCHI FOCUS LENS 98.¹⁵ Another wargaming simulation initiative—the Joint Simulation System (JSIMS)—hopefully will increase logistics emphasis. The JSIMS goal is to be “the primary modeling and simulation tool to support future joint and Service training, education, and mission rehearsal.”^{16, 17}

Constructive Logistics Models

Over the years, logistics has probably benefited more from constructive simulation modeling (such as LCOM) than from virtual simulation efforts. One reason is because constructive simulations are particularly useful for analysis. Logistics problems are frequently too difficult to solve by analytic methods. For example, monthly demand for spare parts is typically random. This demand uncertainty makes an inventory problem much harder to solve than an inventory problem with constant demand and when an analyst must determine optimal stocking levels and reorder points for many parts at once, the problem becomes enormous. RAND's Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC, version 6) was one of the early popular simulation models developed for Air Force problems in repairable inventory theory.¹⁸ Previous, analytic versions of METRIC were based on steady-state conditions that precluded modeling dynamic factors like wartime surges in aircraft usage rates and uncertain support capabilities. Dyna-METRIC can handle these dynamic factors while also accommodating lateral resupply—which is very difficult to

capture in an analytic inventory model. The gains in modeling flexibility from simulation do not come for free, however. Because Dyna-METRIC is a simulation, it cannot optimize spares requirements to achieve specific goals.¹⁹ A more recent inventory analysis simulation example is provided by the Defense Logistics Agency's (DLA) Performance and Requirements Impact Simulation (PARIS) model. PARIS is used to examine investment, inventory and supply chain policies for the more than 1.9 million spare parts that DLA manages. It can simulate two years of demand on 190,000 items in under two hours.²⁰

Inventory problems are certainly not the only logistics problems that benefit from simulation. LCOM is widely used to address a variety of base-level logistics issues including sortie generation rates, personnel requirements and aircraft availability.²¹ For example, the F-22 System Program Office is now using LCOM to estimate sortie generation rates and maintenance personnel requirements.²²

Transportation theory can also benefit from simulation modeling. Air Mobility Command (AMC) uses the Airlift Flow Model (AFM)—a simulation model embedded within the Mobility Analysis Support System—to assess policies for airlift control, mission planning and mission execution. The AFM provides a global airlift simulation of AMC and commercial airlift assets in strategic and theater operations. AFM can simulate airborne refueling, aircrews and their flying hour limits and all phases of aircraft ground handling. Since its development, no serious airlift analysis has been performed without at least comparing the results with output from AFM.²³

Constructive Simulation Tools

Throughout the 1980s, the suite of available simulation tools was pretty limited. Personal computers were not very powerful and few commercial simulation software packages existed. The analyst was mostly limited to writing simulations in a general purpose language (such as PASCAL or FORTRAN [Formula and Translation]), and running the models on a mainframe computer. The result was that simulations tended to be difficult to build and maintain and were seldom interoperable. Things have changed dramatically in the last ten years. Today over 40 different commercial simulation software packages are available.²⁴ The tremendous improvements in personal computer hardware help analysis as well. For example, DLA's PARIS simulation was built using AweSim™ (a commercially available simulation program) and runs on an NT® workstation. PARIS replaces a mainframe computer-based FORTRAN model that was difficult to maintain and change.²⁵

Some constructive simulations can even be run on a standard personal computer spreadsheet! *Monte Carlo* simulations are those in which time has no real relevance to the problem. Instead, the goal is to determine the outcome of a series of random experiments. For example, a gambler does not really care how long it takes to play a series of poker hands. The important aspect is whether the gambler wins or loses each game. If we were to simulate the reliability of an aircraft landing gear over a series of landings, we would be more interested in the landing gear's failure history than on

how long each landing takes. Spreadsheets can readily accommodate Monte Carlo simulations, especially when a spreadsheet *add-in* such as Decisioneering's Crystal Ball or Palisade's @Risk is used. Dyna-METRIC is a (non-spreadsheet based) Monte Carlo simulation.

Simulation Model Credibility

No discussion of simulation is complete without addressing model *verification* and *validation* (V&V). In fact, this topic is so important that the DoD issued *Defense Instruction 5000.61, DoD Modeling and Simulation Verification, Validation, and Accreditation*, in April 1996. The Air Force also has guidance, found in *AFI 16-1001, Verification, Validation, and Accreditation*, dated June 1996. Verification seeks to address whether we have built our *model right* (does our model satisfy our design requirements?), while validation focuses on whether we have built the *right model* (are our design requirements themselves correct?).²⁶

The real goal of V&V is to get the principal users of a simulation model to feel confident about it. The outcome of a V&V effort is *not* a yes/no answer—there is no such thing as absolute validity. We usually do not have enough time or money to check every aspect of a model. Finally, there is no such thing as *general* validity—a model that is valid for one purpose may not be valid for another.

Symbolic models are typically verified by using standard computer programming debugging techniques. Example methods include building and checking a model in logical chunks, starting with a simple model and adding complexity only as needed and ensuring that units of measurement are consistent. Sometimes a simulation model can be simplified, and its output compared with an analytical result.

Validation is generally harder to perform than verification. Validation asks: how does the simulation model compare to reality? We want the model to be *good enough* to use in the same way we would use the real system. This implies that a model's assumptions and limits must be clearly defined and documented, else we risk using the model under conditions that render it invalid.

A key V&V goal is to develop a simulation model with high *face validity*. This means that the model and its output seem *reasonable* to experts in the field. A typical validation method is to compare a model's output to historical data (if available) or to the output from a similar simulation model. For example, DLA compared their PARIS model results to output from the model it replaced, because changes in policy and demand patterns made it impractical to compare PARIS output to historical data.²⁷ Another way to boost face validity is to involve the model's eventual users continuously throughout the model's development. Regular involvement is a great way to promote user *buy-in* to the overall effort and ensures that nobody is surprised over what the final simulation model can or cannot do.

Finally, note that ease of validation depends on the actual system of interest. It would be straightforward to validate a simulation model of some aspect of a current depot's operation, because the real operation is an existing, observable process. Now imagine how we would validate a model of on-equipment maintenance in the proposed Space

Station. The best we could probably do would be to compare our model's output to data from Skylab or the Russian MIR program.

Simulation Education

At least one course on simulation is offered in many graduate schools, including most civilian universities, the Air Force Institute of Technology (AFIT) and the Naval Postgraduate School. AFIT requires that a simulation course be taken by students in logistics masters degree programs. A typical simulation course teaches the *constructive* modeling aspect of simulation—for some reason, little emphasis is placed on *live* or *virtual* simulation. Law & Kelton²⁸ and Banks, Carson and Nelson²⁹ represent the two most popular textbooks on constructive simulation modeling.³⁰

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Conclusion

Virtually every military member is likely to participate in or be affected by a simulation effort during the course of a career. Why? Simulation helps us get the most benefit from our defense dollars. We can use simulation to help warfighters train, to develop doctrine and to perform analysis on almost any military topic. An increasing need exists to be able to integrate *live*, *virtual* and *constructive* simulations into *systems of systems*. The DMSO's common technical framework is the key initiative that will make these systems of systems feasible. Finally, we must never depend on simulation modeling as a complete replacement for working with reality. Real systems contain subtleties and uncertainties that our models will probably never capture completely. However, simulation can give us useful insights at a fraction of the cost and risk.

Notes

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30. Anyone interested in simulation would be well-advised to attend the annual Winter Simulation Conference (WSC), held each December. Virtually every topic in simulation is discussed at the conference and the organizers publish a set of proceedings. For further information on the WSC, visit the Institute for Operations Research and Management Science simulation web site at <http://www.isye.gatech.edu/informs-sim>. Many other great simulation web sites exist. A good V&V site is sponsored by Osman Balci at <http://manta.cs.vt.edu/biblio/index.html>. Bill Yurcik's web site, <http://www.pitt.edu/~wjyst/nsfteachsim.html>, provides simulation education information. The Air Force Agency for Modeling and Simulation's (AFAMS') web site is at <http://www.afams.af.mil/>. The AFAMS, a field operating agency, serves as the Air Force focal point for managing, coordinating and integrating major Air Force modeling and simulation programs and initiatives. Finally, AFMC's Electronic Warfare / Modeling and Simulation Integration Office (EWMSIO) maintains a site at <http://ewio.wpafb.af.mil/>. The EWMSIO serves as AFMC's center for modeling and simulation expertise and integrator of Lab, Product, Logistics and Test Center capabilities.

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